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PATS: PSYCHOPHYSIOLOGICAL ASSESSMENT TEST SYSTEM

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ABSTRACT

This paper describes the development of a new generation of psychophysiological test battery to replace our first battery, the Neuropsychological Workload Test Battery (NWTB). The new battery, the Psychophysiological Assessment Test System (PATS), has a much improved user interface, expanded capabilities for use in simulator facilities, enhanced data reduction and management capabilities, and includes the ability to do statistical analysis.

INTRODUCTION

Optimal operator performance is critical for the functioning of many systems and especially for systems as complex as modern aircraft. However, direct measurements of operator performance to evaluate aviation systems and related subsystems can be difficult to obtain. Instead, human performance is usually inferred by observing its effects on the aircraft. To further aid in measuring performance, the operator is sometimes asked to provide a subjective rating of individual tasks. While subjective rating scales can provide valuable information, their interpretation can be limited by such factors as previous experience, selective memory, and expectations of the operators. Physiological data, however, can provide more direct measures of the internal state of the operator and, as such, can be a powerful tool for the evaluation of aviation systems. Thus, physiological data, which are continuously available and can be collected non-intrusively, can be used to supplement the information provided by performance and subjective data.

For a number of years, heart rate data have been used to evaluate pilot responses to the stresses of flight (Comens, Reed, & Mette, 1988; Roscoe, 1988; Ruffel-Smith, 1967). More recently, physiological measures such as electroencephalograms (EEG; Sterman, Schummer, Dushenko, & Smith, 1988) and eyeblinks (Wilson, Purvis, Skelly, Fullenkamp, & Davis, 1987)

have been collected during flight and found to provide valuable information regarding pilot workload. In addition to the flight environment, physiological measures have also been used to monitor and evaluate operator responses during flight simulation tasks (Lindquist, Keshinen, Antela, Hulkala, Peltonen, Valimoki, 1983). Finally, physiological data could also be used to assist in the evaluation of aviation subsystems such as cockpit designs and head-up displays.

The Psychophysiological Assessment Test System (PATS) was developed to provide a comprehensive and usable test system for the measurement of psychophysiological data. As aircraft and associated systems become even more complex, there is a concomitant need for a multifunctional system to investigate and evaluate psychophysiological data during both simulation tasks and flight. Such data can ultimately be used to improve the design, development, and operation of modern, sophisticated aircraft. Based on a microcomputer system, the PATS is designed to support psychophysiological research in a wide variety of applications ranging from operational environments with real-world tasks to laboratory environments with standardized tests. Thus, the PATS addresses a number of requirements for aviation psychology including multifunctionality in terms of testing environments, research applications, and usability. The PATS evolved from the Neuropsychological Workload Test Battery (NWTB; Wilson and O'Donnell, 1988); but, as the word "system" implies, the new generation represents a more comprehensive approach to the application of psychophysiological measures.

Designed and developed by a multidisciplinary team of human factors psychologists, electrical engineers, and computer science specialists, the PATS has capitalized on recent technological advances in both hardware and software. The PATS is based on an Apple Macintosh II/IIx with the hardware including 8 megabytes (mB) of memory, color graphics, and a 650 mB optical disk. For structured programming, the PATS incorporates "C"; for menu design and implementation, it uses HyperCard. Throughout development of the PATS, the guiding principle was to build a flexible, multifunctional system which could be efficiently operated in a variety of applications and could be readily utilized by novice users with minimal experience in psychophysiology, as well as by experts. Consequently, the system is capable of functioning in either of two capacities: (1) operating as a self-contained unit which can perform all aspects of psychophysiological research from task stimulus generation to complex data reduction and analysis, or (2) serving a more limited role as a single component of a more extensive equipment configuration. Ultimately, the objective was to make the capability of psychophysiological evaluation more widely available, especially for aviation-related applications.

SYSTEM CONFIGURATION

The PATS was designed as a comprehensive psychophysiological system encompassing three general functions: (a) stimulus generation for any combination of tests from PATS' neuropsychological test battery, (b) data collection and storage, and (c) data reduction and analysis. To enhance system availability, all components of the PATS are commercially available. Figure 1 displays a schematic diagram of the PATS components.

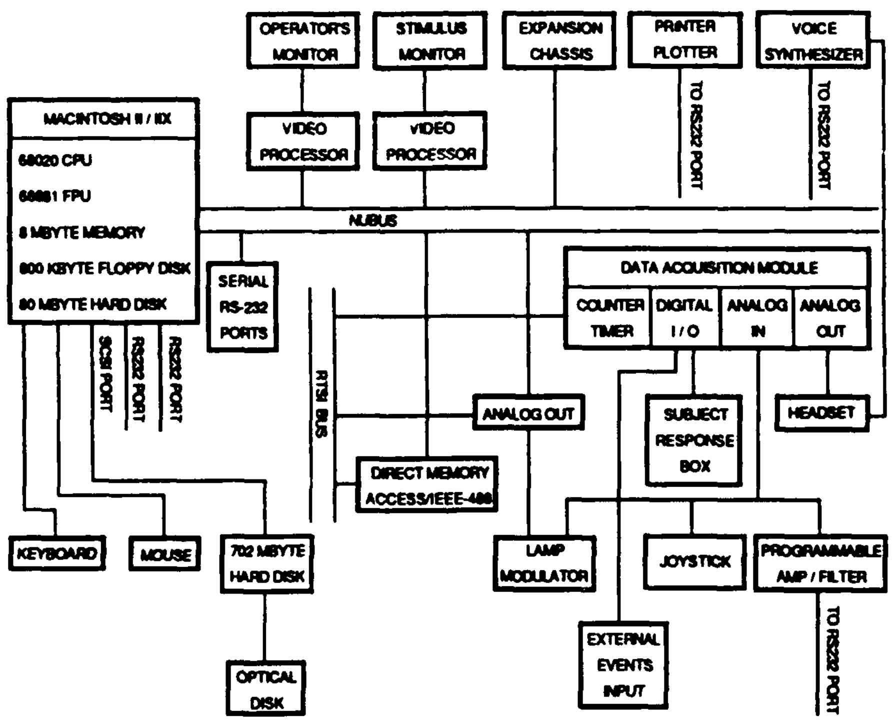

Figure 1. Schematic diagram of the major components of the PATS.

The PATS permits digitization of up to 16 channels of analog data at a 1000 Hz rate for each channel. Thus, the user can monitor and evaluate any variety of physiological responses, including the electrocardiogram (ECG), the electroencephalogram (EEG), evoked potentials (EPs), the electro-oculogram (EOG), the electromyogram (EMG), and respiration. The analog

signals can be amplified and filtered prior to digitization by either standard, commercially available physiological amplifiers or customized, programmable amplifiers. In the former case, the PATS enables the user to readily generate a record of the settings such as gain and band-pass used for each channel. Alternatively, for the programmable amplifiers, the gain, high-pass, low-pass, and 60Hz notch filter can be directly selected and recorded through the computer.

The large data storage capabilities (650 mB optical disk) of the PATS enable continuous data collection for up to 8 hours. Traditionally, psychophysiological data have been collected for discrete time intervals with pauses in the data collection between successive data intervals. The continuous data collection of the PATS ensures that critical data will not be missed during performance of tasks such as simulated flight where the occurrence of specific stimuli or particular task segments are difficult to predict. Additionally, since the continuous data are available, re-analysis with different parameters, such as epoch length or filter characteristics, is easily accomplished.

In addition to the analog data, the PATS can also record up to 32 channels of digital input signals, sampled at 1000 Hz, and can generate up to 16 digital outputs. The digital input lines can be used to record reaction times for subjects' manual responses and/or as event markers to register the occurrence of stimuli presented by another system or simply to mark relevant data segments for later analysis. For example, during a flight simulation task digital input lines could be used to record emergency warnings or to identify portions of the psychophysiological data corresponding to specific mission segments in the simulation such as course corrections. In the opposite communication direction, the digital output lines can be used to trigger external devices and to ensure synchronization between systems, if the PATS is being used in conjunction with other equipment. For example, digital outputs could be used to mark on the simulator log the occurrence of PATS-generated stimuli. Finally, to further enhance the interface capabilities of the PATS, four RS-232 ports are available for serial transfers between systems and an IEEE-488 port for parallel transfers.

USER INTERFACE

One potential disadvantage of a highly flexible, multi-functional system is that the required number of user entries can increase to the point where the system lacks user-friendliness. This issue is even more critical for the PATS since one of the objectives was to develop a system with extensive menu options that would be useful to researchers

with experience in psychophysiology or those with limited psychophysiological training.

Several approaches to optimize the usability of the system were incorporated into the PATS. First, the user interface was developed in HyperCard utilizing a menu hierarchy and featuring a flexible navigational route which does not restrict the user to a specific order of operations, nor require multiple exit commands to return to a higher level in the hierarchical structure. To minimize user disorientation within the system, the depth of the hierarchy never exceeds three levels.

A second feature to optimize the usablity of the PATS is the extensive error-checking provided throughout the user interface. The error-checking is performed on multiple levels with syntax and out-of-bounds errors being detected immediately, and more comprehensive logic errors being reported when the user requests a compatibility check. Thus, for example, a letter entry in a number field will be detected immediately. In contrast, a logic error will occur if the user selects a digital input channel, which has not yet been configured, to trigger presentation of task stimuli to the subject. At the time of the selection a warning will be displayed along with the option to immediately configure the channel. Later, when the user selects the compatibility check, if the digital input channel is still not configured, an error message will be presented.

A third usability feature of the PATS is thorough documentation. There are two user's manuals for the PATS. One is an operator's manual that describes the mechanics of how to use the PATS and provides concrete examples. The other is a reference manual that details the purpose, description, background, and instructions for each of the stimulus-generating tests included in the PATS. In addition to the manuals, there is a directory-guided, on-line help system to answer questions pertaining to the user entries on the menus.

The menu portrayed in Figure 2 has the specific function of enabling the user to specify the physical parameters of the standard tone in an auditory rare event test. However, it is also illustrative of a number of general principles of the PATS user interface. The icons at the top of the screen perform the following functions (from left to right): print screen, save file, present tone, return to previous screen, access help directory, and return to home screen. With the exception of the headphones icon which allows the user to immediately hear and evaluate the tone, these functions are available on all of the screens. Rectangular boxes indicate keyboard entries, while all other selections are made by clicking a button on the mouse. Different types of buttons

reflect different functions. For example, oval buttons at the bottom of the screen are navigation buttons which go to other menus. In this case, "save values" will change the tone parameters to those currently displayed on the screen and return the user to the main menu for the auditory rare event test. When appropriate, simple diagrams, like the one shown here indicating the segments of the tone envelope, were used for clarification.

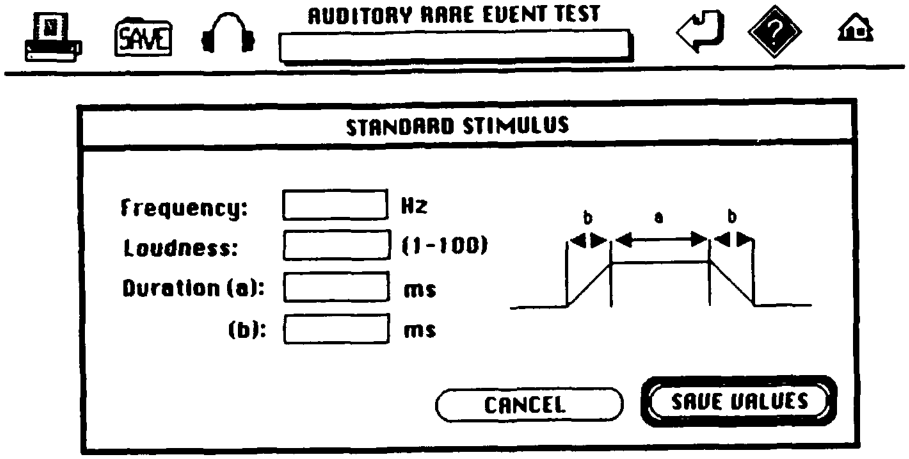

Figure 2. A sample menu from the PATS.

TESTS

Prior to data collection, the user configures the analog channels for digitization of physiological data, and designates digital input and output lines to be used during data collection. All analog and digital data will be continuously sampled throughout data collection. In addition to all of the physiological tests for EEG, ECG, EOG, and respiration, the user may also, simultaneously, have discrete stimulus tests presented to the subject. The user selects which tests will be used, when they will be started (by time, external event, or a combination of these two), how long each will last, and what the particular stimulus parameters will be for each test. Several stimulus tests may be incorporated into the session file with each test being presented sequentially or with two tests being presented simultaneously, if the stimuli of one test are auditory and the stimuli of the other test are visual. Thus, a session file contains all of the information necessary for data collection including analog and digital connections and test stimulus parameters. Once the session file has been generated, it can be used over and over for each subject in an

experiment. Alternatively, an existing session file can be edited to make changes for another experiment.

The list of tests available to the user is broadly categorized into two groups: (1) evoked potential (EP) tests with discrete stimuli and (2) continuous data tests without stimulus presentations. Within the evoked potential tests there are sensory tests which do not require behavioral responses from the subject. The sensory tests include a checkerboard pattern reversal test, an unpatterned steady state test using flickering lights, and a brainstem auditory response test. Another group of tests within the evoked potential category are performance tests which do require behavioral responses from the subject. The performance tests include auditory and visual versions of a continuous memory test, auditory and visual versions of a Sternberg memory scanning test, auditory and visual versions of a rare event (P300) test, an auditory test on selective attention, a visual monitoring test, a manual tracking test, simple tone or flash presentations, and a user-defined test with both auditory and visual stimuli.

The user-designed evoked potential test is of special interest. This test allows the user to design a discrete stimulus test, with up to 6 stimulus categories, 5 different stimuli per category, and a separate probability of occurrence for each category. Both auditory stimuli, such as tones and synthesized speech, and visual stimuli, such as letters, shapes, and checkerboards, are available. The purpose of this test is to permit users flexibility in the types of tests that can be used and not restrict them to only those tests currently implemented on the PATS. This test, like the other performance EP tests, allows for the input of behavioral responses from the subject and response error checking.

The other group of tests, the continuous data tests, allow for the digitization of a variety of physiological responses including EEG, EOG, ECG, EMG, and respiration. Since no stimlui are presented to the subject during these tests, in the data acquisition section of the PATS the user simply identifies the type of signal input for each analog channel. These tests may be used simultaneously with the stimulus-generating evoked potential tests, if required. In the data analysis section of the PATS, a number of techniques are provided to support off-line evaluation of continuous physiological data.

DATA ANALYSIS

Throughout the data analysis process, the original raw data

are maintained intact on the optical disk and selected data segments are copied to working memory for data processing. At any point in the data selection, editing, and reduction process the data can be viewed on the PATS color monitor. Low-resolution scanning may be used for an overall view of the data, or the zoom function can be used to provide a more detailed examination of smaller data segments. Hard copies of the data can readily be obtained from the system's color printer, and the results of any data processing step(s) can be stored in a permanent file on the optical disk or maintained in a temporary, working file as strictly an intermediate step to further processing.

Appropriate data segments are selected for analysis with reference to the time of data collection or the occurrence of digital input events. Once the beginnning and end points of the data segment have been identified, further refinements of the data segment can be made by selecting the analog and digital channels to be included and the relevant peri-stimulus time intervals for discrete stimulus trials or epoch durations in the case of continuous data without stimuli.

After the data segment has been parcelled from the raw data file, a variety of editing options for both stimulus-related and continuous data are available to the user. Artifact rejection can be performed based on user-specified amplitude criteria of EOG, EMG, and/or EEG signals. In addition to artifact rejection which can result in a significant loss of data, mechanisms are also available for the correction of ocular artifacts in either stimulus-related, evoked potential (EP) data or continuous EEG data. Decimation can be performed on any analog data to effectively reduce the data collection sampling rate of 1000 Hz. Smoothing functions are also available with options for either a weighted or unweighted moving average; and digital filtering algorithms, operating in either the time domain or the frequency domain, provide the offline capability for low-pass, high-pass, or band-pass filtering. A baseline correction option is also available for stimulus-related data.

Another analysis feature of the PATS is called "combine waveforms". This feature enables the user to average, subtract, or add waveforms from stimulus categories within a file, combine waveforms across files, or combine channels within a file. Also included is an option for the user to re-order or reconfigure analog input channels. This option is particularly useful if grand mean EPs are being generated from several subjects who differ in their analog input configuration. Thus, the combine waveforms feature enables the user not only to readily generate average evoked potentials, but also to generate difference waveforms with the subtraction option.

A fourth analysis feature of the PATS essentially provides a mechanism for reducing the complex waveforms of physiological data and generating data tables which can be submitted to the resident statistics package (SyStat) for statistical analysis. The reduction feature includes, for example, a peak-picking function for identifying and measuring the amplitude and latency of peaks in evoked potential waveforms. Other functions within the reduction feature allow for spectral analysis of continuous data, R-wave detection and interbeat intervals of cardiac data, summary parameters of eyeblinks such as closing duration, and reaction time and accuracy of performance data. The data tables generated by these functions, and others, within the reduction feature can then be directly submitted to SyStat which provides both descriptive and inferential analyses of the data and has extensive graphic capabilities. Since the PATS can perform all aspects of the data analysis, only one machine is required for the entire experiment, precluding the need to transfer data to another computer. If, however, the user wants to either import data from another computer for analysis on the PATS, or export data from the PATS to a mainframe, these data transfers can be easily accomplished using either an RS232 port for serial data transfers or an IEEE4888 port for parallel data transfers.

After the user has identified each procedure and the parameters required for analyzing a particular data set, the analysis can be automated. That is, the user can construct a command file by selecting, from a previously generated list of steps, the order of procedures and the parameters to be used and by designating the input and output data filenames. The command file can then be initiated for large volumes of data without necessitating user interactions with the system at intermediate steps.

APPLICATIONS

While the PATS can be operated as a self-contained unit, provisions were also made to allow the PATS to interface with other systems, thus providing readily available access to any subset of PATS' capabilities. Figure 3 presents a schematic diagram depicting three possible applications of PATS.

In the standard laboratory application, PATS may be operated as a self-contained unit and perform all three general functions. A second possibility, one which is particularly likely in simulator applications, is to have another system (the simulator) generate and present the task to the subject and use the PATS for psychophysiological data acquisition and analysis. A third potential use for the PATS pertains especially to field applications where the subject is per-

forming an operational task and the psychophysiological data are being collected on a portable data recording device. The data could then be imported to the PATS for data reduction and analysis.

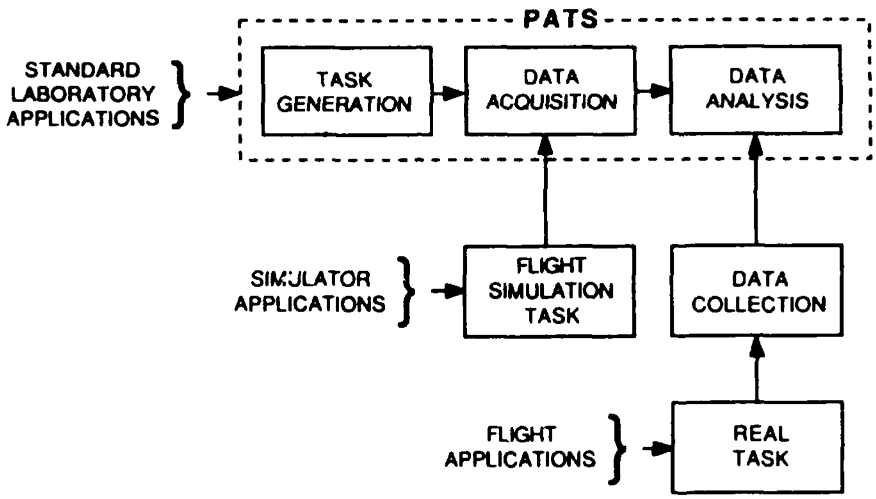

Figure 3. Applications of the PATS.

Although Figure 3 presents only three potential configurations, many others are possible. For example, in standard laboratory applications the task could be presented by another computer and the function of the PATS could be limited to data acquisition and analysis. Event markers, coincident with stimulus onset, could be sent from the task computer to the PATS to allow for synchronization of the task stimuli and the psychophysiological data. Another possibility would be to use the PATS as a continuous data collection device without the subject being engaged in a discrete stimulus task. The multiple serial and parallel input/output ports and numerous digital inputs and outputs of the PATS were specifically designed to facilitate this wide variety of potential applications and equipment configurations.

In addition to supporting a variety of application environments, the PATS was also intended to support human factors research in a variety of topic areas. For example, the PATS with its flexibility and usability could greatly facilitate the collection and evaluation of psychophysiological measures in such areas as: workload, chemical defense, human/machine interface, visual display evaluation, flight simulation, cockpit design, sustained operations, and

fatigue.

SUMMARY

The purpose of the PATS is to meet a need for a multiple function psychophysiological system that is easy to use, but has extensive capabilities and permits flexibility in terms of application areas. Based upon our past experience with an earlier system, we have developed the PATS to meet this need. The PATS provides the capability of running an entire experiment from stimulus presentation to statistical analysis, yet has the flexibility to operate in many environments which require fewer functions. Modern computer technology has made possible the development of this sytem, and it is our hope that it will be widely utilized.

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